Comparison between surface and VSP reflection imaging of shallow sites NS2.3

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SUMMARY

We compared surface geophone shot records with multi-offset VSP hydrophone records at a bay margin depositional environment site, characterized by a complex interleaving of largely unconsolidated clay, sand, gravel and mud layers. The aim being to determine which seismic method was better suited to produce a reflection image between 3m (water table) and the basement at 35m, suitable for structural interpretation. We discovered that the VSP data had at least three times the bandwidth of the surface data, with lower levels of cultural noise. One of the most important advantages of VSP is the ability to resolve reflections from shallower depths than is possible with surface reflection techniques, and we determined that at this site we would not be able to image reflections above 20m. Additional advantages of using offset VSP imaging included accurate time-to-depth conversion, deterministic statics, and with reliable velocity control. We used inter-hydrophone baffles to attenuate and slow down tube waves, which facilitated reflection wavefield separation, and increased the recorded signal bandwidth. The VSP-CDP mapped image ties in well with cone penetrometer logs, and clearly shows reflections from thin gravel and sand units between 5m and 35m, with an inter-bed resolution of 0.5 m, out to a distance 9 m from the well. The mapped image also clearly shows lateral bed discontinuities, interpreted to be sand/gravel lenses and pinch-outs.

INTRODUCTION

There has recently been a resurgence of interest in near-surface geophysics due, in part, to the subsurface cleanup effort at government, military and industrial sites. Unlike the petroleum industry, where seismic reflection imaging makes up more than 95% of the geophysical investment, seismic reflection imaging is a relatively small component of the near-surface geophysics industry, and refraction surveying still appears to be the principal technique used in near-surface applications.

In this experiment, we compared the use of multi-offset VSP ,recorded using a sledgehammer source and hydrophone receivers, against surface geophone line records, shot with a Betsy gun source, for near surface imaging at a shallow clastic site on the shores of San Francisco Bay. We began by comparing the frequency content obtained from VSP to that obtained from the surface data. We then evaluated the quality of the reflection signals from both the surface and VSP surveys, and estimated the minimum depth at which surface reflection imaging was possible at this site.

SITE DESCRIPTION

We collected multi-offset hydrophone VSP data, and surface seismic data at the Richmond Field Station, near Richmond, California. The Richmond Field Station is located about 300m from the north east shores of San Francisco Bay, and the geology there consists of quaternary shales (commonly known as bay muds) and sandstones extending from the surface down to the Franciscan basement at a depth between 30m to 40m. This region can be broadly described as fresh deltaic depositional, consisting largely of unconsolidated and interleaved mud, clay, sand and gravel lenses, presenting a laterally heterogeneous structure. The mean water table depth was about 3m at the well site where we collected seismic data.

DATA ACQUISITION

We collected surface-to-surface shot records into two geophone lines across the well site. Geophone spacing was 0.5m, and records were shot in a walk-away noise-test mode, with offsets ranging from 3m to 63m over 120 channels. We used both a hammer-on-plate source, and a Betsy Gun source with 8 gauge and 12 gauge shotgun shell blanks, inserted about 1m down an auger-drilled hole.

For the VSP survey, we lowered our 0.5m spaced, 24 hydrophone string down a 6 inch diameter, PVC cased well with a TD of 70m. We positioned the hydrophones between 5.0m and 16.5m depths, and recorded 15 SPs, spaced at 1.2m intervals, starting at minimum offset 1.2m, with the last SP at offset 18m. We then repositioned the hydrophone string down 12m, to cover depths between 17m and 28.5m, and all 15 SPs were repeated. A hammer-on-plate source was used as the source.

From initial analysis of VSP records at this well site, we determined that tube waves were the major coherent noise source, leading to difficulty in wavefield separation of the reflection energy. To attenuate and slow down the tube waves, we added closed-cell foam baffle material to fill the gaps between each hydrophone element, as well as extending about 2m above the first element. This technique was also used by Pham (1993). The closed-cell foam was in the form of 0.5 inch pipe insulation sections. The outside diameter of the foam tubes was about 1.75 inches, similar to that of the hydrophones. Slowing down and attenuating the tube waves later facilitated wavefield separation processing, and increased the record bandwidth to almost 1kHz.

For both surface and VSP surveys, a 48 channel Geometrics portable recorder was used, running off automotive batteries, with 0.2ms sample interval, and a low-cut filter at 35Hz with 18dB/octave slope.

DATA COMPARISON BETWEEN SURFACE & VSP

Figure 1 shows a surface CSG (common shot gather) shot with a 12 gauge Betsy gun source, after band pass filtering (80Hz - 600Hz) to remove ground roll, then AGC, and spiking deconvolution to remove multiples, and try and resolve reflection arrivals. Figure 2 shows two VSP CSGs from SP offsets 4.8m and 7.2m, processed in a similar manner to figure 1, except using a bandpass of 150Hz - 1200Hz due to the greater available bandwidth. Figures 3 and 4 show the f-k spectra of the surface CSG, and a VSP CSG respectively, and it is immediately apparent that the VSP data has more than 3 times the bandwidth of the surface data (900Hz vs. 250Hz).

Reflection arrivals can be clearly seen in the VSP data (figures 2 and 4), but not in the surface data. At this site, with an average velocity of 1650m/s between 10m and 30m, a reflection event from 10m depth would occur at about 13ms (2-way time), and it can be seen from figure 1 that at this 2-way arrival time there is strong coherent noise interference in the form of aliased air wave and shallow direct arrivals with apparent velocity 480m/s. To avoid the coherent noise, only 2-way times greater than 25ms could be used for stacking, which corresponds to a minimum reflector depth of about 20m.

Large static shifts are also apparent in the surface CSG of figure 1. Note the short (10m to 20m offset) sub-set of refraction arrivals which do not appear to have much significant static time jitter; this was where the geophone line crossed a well packed gravel road of slightly higher elevation to the surrounding field. In other surface surveys, we experimented with buried geophones, and observed much smaller inter-geophone statics. In VSP offset reflection imaging, static corrections are only required for shot point locations, and can be determined from the direct wave first break picks.

VSP-CDP MAPPING OF REFLECTION ARRIVALS

We used wavefield separation techniques to isolate and enhance reflection arrivals in the VSP data. Figure 5 shows an example of a processed CSG prior to mapping. A 1-D velocity map was created for the VSP-CDP transform by inversion of the first-break time picks, at near SP offsets, into an interval velocity map, using a ray tracing program. From these near-offset interval velocity maps, a best estimate velocity map was generated, and then ray-trace matched to each shotpoint's CSG first-break picks by adjusting the top layer interval velocities only, effectively doing a static correction for each shotpoint. Each processed CSG, starting at 2.4m offset, was then transformed into a z-x section. These sections were then amplitude balanced, and stacked, after minor vertical alignment adjustments (< 0.2m) to increase stack coherency. Figure 6 shows the final VSP-CDP stacked reflection image for this site.

Two cone penetrometer logs (CPT1 and CPT4) have been spliced into the mapped section of figure 6 at the correct offset distances from the acquisition well. Each CPT log consisted of a bearing load trace, sleeve friction trace, and DC resistivity trace; these have all been gray-scale converted together with the mapped image in figure 6: increasing darkness means increasing bearing load, increasing sleeve friction, and increasing resistivity, directly leading to the interpretation of a fresh water saturated sand or gravel. The CPT1 log stopped at just below 20m because of too much bearing load, indicating a stiff gravel/sand layer, which is probably a major aquifer because of the high resistivity. No phase shifting has been applied to the mapped image wave form to align it in any particular way with the CPT log data.

CONCLUSIONS

We believe that high resolution offset VSP offers a viable means of economically reflection imaging shallow structures, either for ground water control, hazardous waste control, building foundation control, etc. The main advantage over surface methods is at least a doubling of the potential vertical resolution, and the ability to image reflections above 20m - 30m. VSP enables accurate correlation and identification of reflection horizons with existing well log data. Important geological structures on the order of less than a meter thick may then be interpreted laterally away from the well, out to a distance approximately equal to the depth of interest, with minimal loss of resolution.

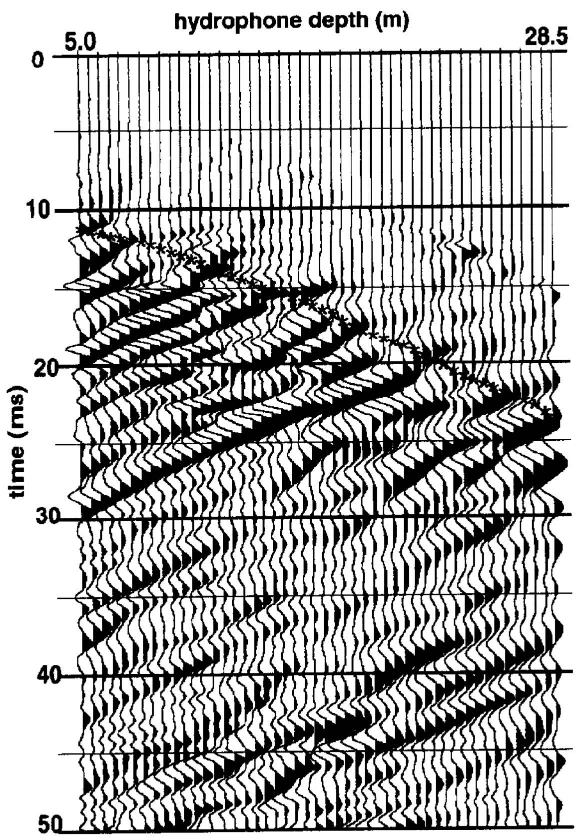

figure 5: Example of 48 trace CSG at SP offset 7.2m prior to VSP-CDP mapping

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REFERENCES

Hardage, B.A., 1983: Vertical Seismic Profiling, part A, principles: Geophysical Press, 450pp

Pham, L.D., Krohn, C.E., Murray, T.J., Chen, S.T., 1993, A tube wave suppression device for cross-well applications: 63rd Annual Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, SEG, 17 - 20.

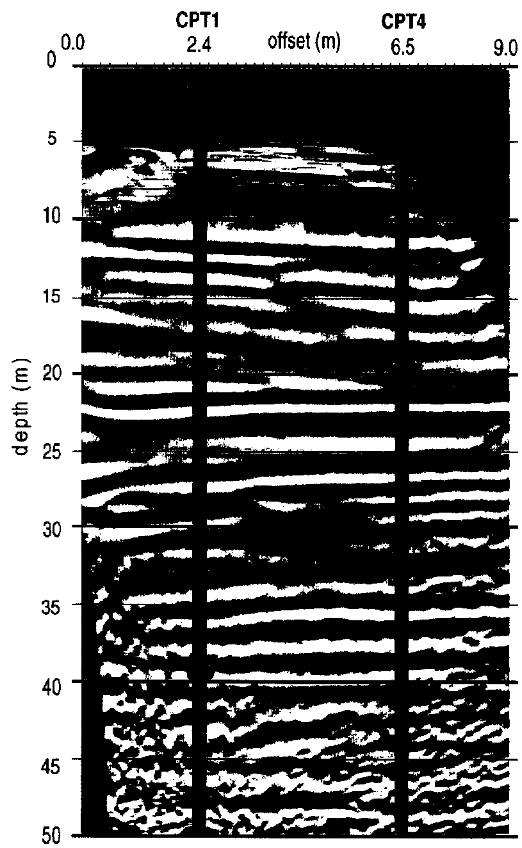


Figure 6: Final stack of VSP-CDP mapped images.

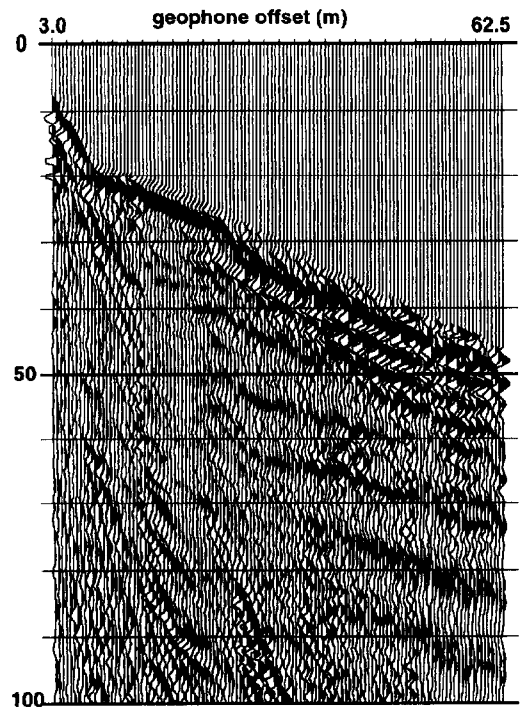


Figure 1: Surface CSG, 120 trace, after BPF 80Hz - 600Hz, AGC, and spiking deconvolution

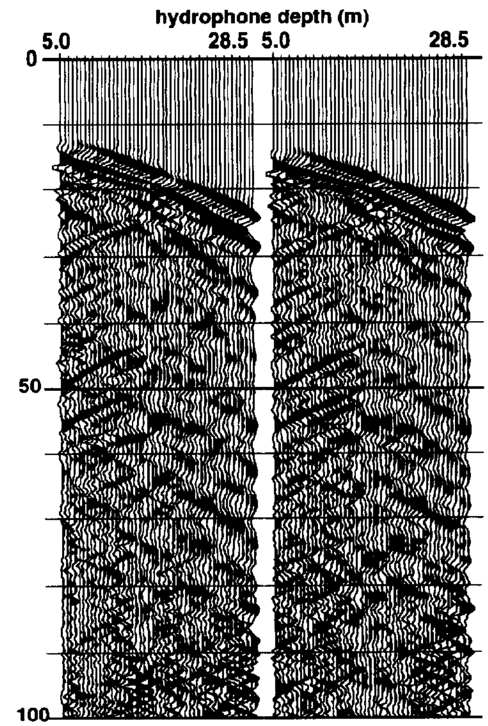


Figure 2: Two 48 trace VSP CSGs, after BPF 150Hz - 1200Hz, AGC, spiking decon.

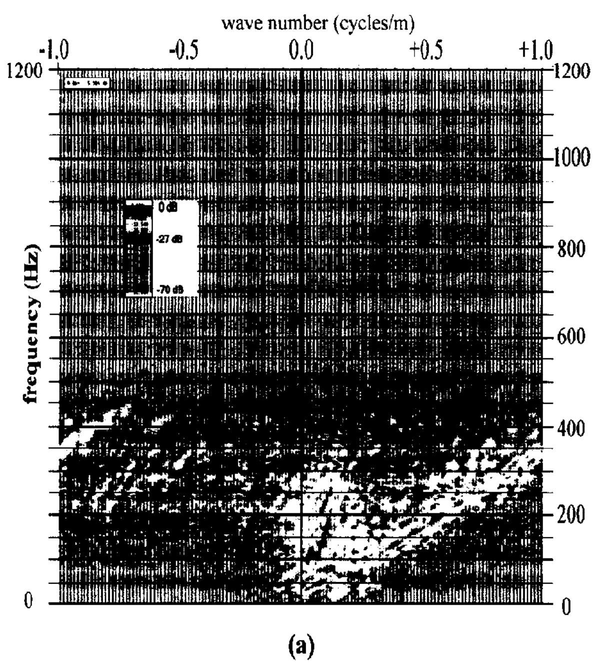


Figure 3: f-k spectra of deconvolved surface CSG showing useful bandwidth & air wave spatial aliasing

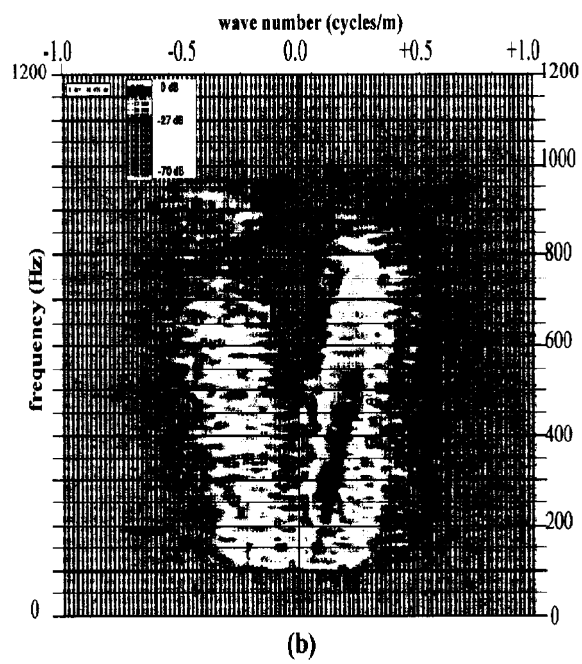
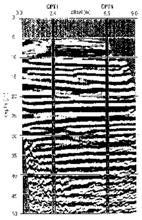
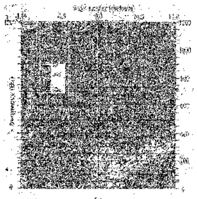
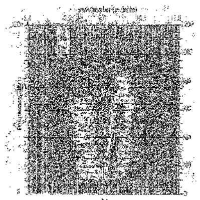


Figure 4: f-k spectra of deconvolved VSP CSG showing useful reflection signal bandwidth.


CPT1
CPT4
2.4
6.5
9.0



(a)



(b)